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Energy Engineering of Hybrid Dryer System based of Exhaust Gases and LPG Integrated with Rice Milling Unit

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***Abstract*—The purpose of this paper is to calculate an energy engineering of hybrid dryer based of exhaust gases and LPG, integrated with rice milling unit using a cogeneration system for utilization diesel engine exhaust gas temperature at the power plant of rice milling unit for paddy drying process and LPG burners. The method used is to measure the temperature and mass flow rate of the exhaust gas of a diesel engine and capacity of dryer for calculating heat exchanger design. Results of measurements at 120 kVA diesel engine exhaust gas temperature at 357 °C and the mass flow rate 636 kg/h. From the calculation results, power that can be generated by the exhaust gases are 56 kW and heat required for drying are 24 kW/ton. The total grain can be dried is 2 tons. Selection of LPG burners adjusted to results of the calculation of the energy need for drying capacity of 1 to 2 tons is gas burners wich can operate in the power range 23 kW to 58 kW. The use of LPG burner only when the drying process is still underway and the rice milling process ha stopped operating before drying target is reached. This study shows that the exhaust gas of a diesel engine can be applied to the dryer with a cogeneration system.**

Keywords: Grain Dryer, Energy, Cogeneration, Sustainable, Heat Exchanger, Waste Heat, Rice Milling.

I. INTRODUCTION

Abundance of rice yields at the same time by the operation of the rice combine harvester if not managed properly can result in poor quality grain. Stacking amount of grain in a long time should be supported by dryer system of grain that can be operated cheaply and in sufficient quantities to be able to accommodate the entire crop until the required time.

Harvest grain moisture content varies between 18-25% wet basis, if not dried quickly will reduce the quality of grain. Drying to reduce the moisture content to about 14% wet basis so that grain can be stored for longer, facilitate the milling process and to produce good quality rice.

Energy for the drying can be obtained from several sources, namely the burning of fossil fuels, electric power, solar energy, gas or biomass and other sources. Imprecision in the selection and use of energy resources could increase production costs and decrease efficiency.

The distance between the location of the accumulation of grain drying is also quite difficult for farmers, and therefore the use of dryer should be integrated with the rice milling unit and use the energy that is cheap and efficient in order to be more effective and can reduce operating costs. Once enough farmers to transport grain drying for milling or directly to sell their dried grain or rice.

A. Diesel engine

In a diesel engine combustion cycle, there is the energy balance of fuel combustion, 35% of energy used as the work, 20% of the energy is lost as the engine coolant, 10% is lost by radiation and 35% is lost with the exhaust gas [1]. Quality waste heat from the flue gas are high temperature, and the greater potential value for heat recovery [2]. Heat lost with the exhaust gas of 35% is a potential that can be utilized for various purposes such as for steam power plants, foodstuffs and agricultural products dryers, heating, or for other purposes. Exhaust gas from Diesel engine is the pollution that contaminates the environment like CO, HC, NOx, Sulfur compounds, Organic Acids, Ammonia, Aldehydes and solids [3].

There are two main criteria to utilize exhaust gas as a heating are exhaust gas temperature and exhaust gas mass flow rate. Diesel engine exhaust gas temperature can reach 500 ° C depending on the power and load variations. Exhaust gas mass flow rate correlated with the amount of engine power, the volume of a cylinder, engine rpm, as well as the fuel air ratio.

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B. Cogeneration

Cogeneration is a system that allows the generation of heat and electrical energy simultaneously from a single system of primary energy. Equipment used to support the cogeneration system is heat exchangers. This system can be designed with configuration of power generation by diesel engines, while the heat generated by utilizing exhaust gas. Overview comparison of efficiency between the conventional energy system with a cogeneration system as shown in Figure 1, where the conventional system, the system efficiency is 58%, while the cogeneration system can be obtained the system efficiency up to 85% on resource use and fuel consumption are similar between needs power generation and heating [4]

The use of heat exchangers for drying grain in rice milling unit is a cogeneration system which can generate hot air and the driving force of the diesel engine can be used for drying grain and rice milling

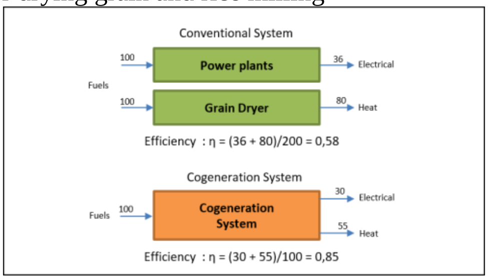

Figure 1. Comparison of efficiency of conventional systems and cogeneration systems [4]

This system can produce an integrated production process between drying and milling process continuously and efficiently without being affected by climate change and the intensity of the sun, and the environment friendly. Waste heat recovery schemes exhaust gas of diesel engines for grain drying with cogeneration technology as shown in Figure 2.

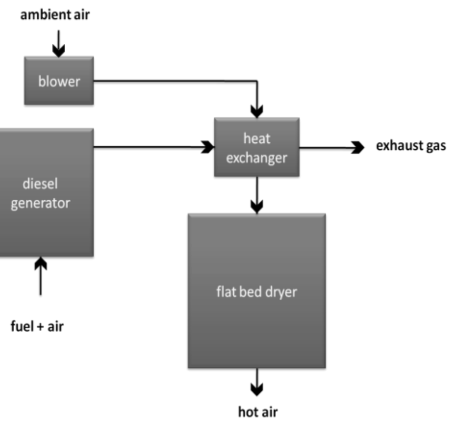

Figure 2. Schematic utilization of diesel engine exhaust gas heat for drying with cogeneration technology

C. Heat exchangers

The exhaust gases of diesel fuel containing pollutants and contaminants that are toxic, so it is not safe when used directly as the drying air in foodstuffs.

The use of heat exchangers is one of the technologies to separate heat and pollutants contained in exhaust gases, which can generate hot air that is clean, free of smoke, dust and ash that food protected from contamination.

Based on the construction and characteristics, heat exchangers differentiated into several types, ie shell and tube, double pipe and compact heat exchangers.

In the grain drying with cogeneration systems, heat exchangers will be placed in the room with limited area, so that the dimensions of heat exchangers are also factors that must be considered.

Furthermore, the selection of heat exchangers should be adjusted to the characteristics of the fluid. For use in drying grain in rice milling unit, the fluid is the exhaust gas as a hot fluid and air as cold fluid. Cross flow plate fin heat exchanger is an appropriate option, as shown in Figure 3. Heat exchangers of this type have several advantages, among others: large heat transfer surface per unit volume of the core, small dimensions, material is easy to obtain, high effectiveness, suitable for gas fluid on both sides and no possibility of contamination between the two fluids.

Figure 3. Cross flow plate fin heat exchanger

D. Hybrid Grain Dryer Based Exhaust Gas and LPG

Hot air obtained from the exchange of heat between the exhaust gases of diesel engines at high temperature, with clean air that flowed in the cross flow heat exchangers.

The utilization of the diesel engine installation rice mill can produce an integrated production process between drying and milling process continuously without being distracted by the effects of weather. The use of LPG (Liquefied petroleum gas) burner only when the drying process is still underway and the rice milling process ha stopped operating before drying target is reached.

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Dryer for hybrid grain dryers based exhaust gas and LPG is a flat bed dryer as shown in Figure 4. This type is simple mechanical dryers, consisting of bed dryer, plenum chamber, heater and blower.

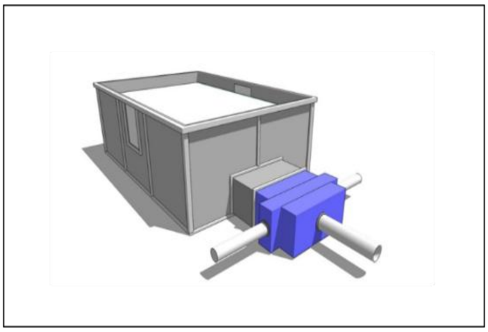

Figure 4. Flat bed dryers

In the hybrid system based dryer exhaust gas and LPG, the heat of combustion of LPG supplied to the dryer by a blower which is driven by an electric motor through air inlet heat exchangers. Installation of hybrid schemes dryer exhaust gas - LPG shown in Figure 5.

The flow of hot air from both heat source arranged in series, one after another poured into plenum chamber dryer at temperatures between 43-55 ° C. The setting is based on the operating schedule of the diesel engine, while the milling process progresses, grain drying process using a source of heat from the exhaust gas of diesel engines, if diesel engine when stopped operating before the end of the grain moisture content is reached, then the flow of drying air is supplied from LPG burner.

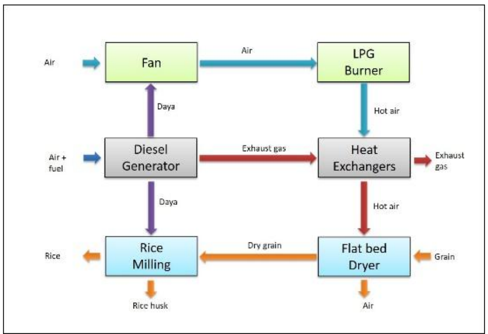

Figure 5. Schematic installation based hybrid dryer exhaust gas and LPG integrated with rice milling unit.

II. CONCEPTUAL FRAMEWORK

The low quality of grain crops due to the accumulation of grain that lasts 7-15 days before being dried [5]. Mileage and transport facilities from the harvest site to the location of inadequate drying has contributed to the decline in the quality of grain crops resulted in lower selling prices of grain at the farm level. Using dryers which can move up to the location of the harvest is also constrained by high operating costs because they have to use fossil fuels.

The use of LPG fuel for a variety of industrial and household purposes, are now quite widely used. The advantages of using LPG as fuel is as a cleaner and cheaper. The exhaust gas of diesel engines is a waste that pollute the environment in the form of pollutants and the hot air at high temperature levels. When properly managed, this waste has the potential to be used as a source of free energy for drying grain for rice milling units, especially those using diesel as an energy source.

Merging both drying systems, exhaust gas and LPG, an alternative to produce a system of continuous dryers and cheap and environmentally friendly. This system can be called a hybrid grain dryer exhaust gas and LPG. The conceptual framework of research for hybrid dryer exhaust system and LPG is shown in Figure 5.

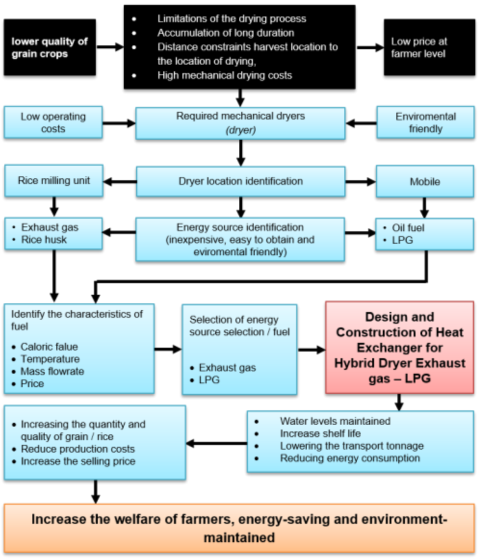

Figure 6. Conceptual Framework research

III. MATERIALS METHODS

1. Identify power diesel engines used by rice mills as a source of energy.
2. The data collection form, the exhaust gas temperature and mass flow rate of the exhaust gas of a diesel engine is used.
3. Designing heat exchangers in accordance with the results of potential measurement of exhaust gas from diesel engines are used.
4. Collect data on the LPG burner characteristics and manufacturer's literature.
5. Determine the type and characteristics of the burner according with grain drying capacity of the exhaust gas energy.
6. Designing systems hybrid grain dryer based exhaust gas and LPG integrated with rice milling unit.

Data retrieval characteristics of diesel engine exhaust gases at Haikal rice mill in the Buluwattang Village, District Pancarijang, Sidenreng Rappang, South Sulawesi research started in June 2015.

IV. RESULTS AND DISCUSSION

In the example of the calculation of the energy requirements of drying, the drying capacity is planned for 1 ton of grain with an average moisture content of 25% wet basis, dried to achieve moisture content of 14% wet basis. Ambient air temperature used in the calculation is the

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average air temperature in South Sulawesi 27ºC, relative humidity with an average of 82% [6].

Defined drying air temperature is 53 °C, during the drying process takes place, it is assumed dryer exit air temperature is 43ºC. To maintain the condition of the grain that are not damaged, estimated drying process lasts for 8 hours.

Calculation of the energy requirements of drying:

From the properties of air can be obtained through the psychrometric chart as shown in Table 1.

TABLE 1. AIR PROPERTIES FROM PSYCHROMETRIC CHART

Caracteristics	Normal	In	Out	Unit
Dry bulb temperature, Tbk	27	53	43	ºC
Wet bulb temperature, Tbb	24.56	30.54	30.54	ºC
Relative humidity, RH	82	20.44	41.3	%
Humidity ratio, H	0.0185	0.0185	0.0231	kg/kg
Enthalpy, h	74.39	101.44	101.44	kJ/kg
Spesifik Volume, v	0.8766	0.9526	0.9295	m^3/kg

We obtained,

Initial water weight = 25% x 1,000 = 25 kg

Dried grain weight = 1,000 kg – 250 kg = 7,500 kg

Final moisture content = (weight of the final water / material weight) x 100

14 = (100 X) / (X + 750)

X = 122 kg

End water weight = 122 kg

Amount of water that evaporates = 250 kg – 122 kg = 128 kg

Evaporation rate (ER)= 128 kg/8 h = 16 kg/h

Rate of air drying (RD) = $\frac{ER \times v_1}{\Delta H}$ = 0.85 $m^{3/}s$

Needed of heat = $\frac{RD \times \Delta h}{v_1}$ = 24 kW

24 kW of heat obtained from the exhaust gas of a diesel engine or LPG combustion either hybrid or separate from any source of energy used

The energy used in the process of grain dryer is a combination of two sources that are from the exhaust gases from diesel engine and LPG burner.

Both use of energy resources take place in series hybrid alternating between the exhaust gas and LPG. The drying process begins by using the exhaust gas heat source until the rice milling operations is finished. When the drying process is in progress not yet finished when the milling process is finished and the operation of the diesel engine is stopped, then continued with the drying process using LPG gas energy to reach the final moisture content of grain desired.

Specifications of diesel engine is used as the driving component of rice milling unit production capacity of 2 tons / hour is as follows Mitsubishi 6D16. Based on the measurement result, the exhaust gas temperature reaches a temperature of 357 ° C at 80% engine load. Exhaust gas mass flow rate is 636 kg / h.]

Power that can be generated by the exhaust gases are:

$q_{eg} = \dot{m}_{eg} * Cp\,(T_2 - T_1)$

Where:

$\dot{m}_{eg}$ = Exhaust gass mass flowrate = 0.177 kg/s

T_2 = Exhaust gas temperature = 357 ºC

T_1 = Drying temperature = 53 ºC

Cp_{eg} = 1,0448 kJ/kg at 205 ºC

Thus obtained exhaust gas power;

q_{eg} = 0.177 kg/s x 1.0448 kJ/kgºC x 304 ºC = 56 kW

In the previous calculation, for drying 1 ton of grain of a moisture content of 25% to 14% wet basis in the drying temperature 53ºC and the relative humidity 82%, requires a power of 24 kW, the total grain can be dried by the exhaust gases of diesel engines loading of 80%, is 56 kW / 24 kW / ton = 2.3 ton. Taking into the effectiveness of heat exchangers and efficiency of the system, the selection of drying capacity is set at 2 tons.

LPG heating value of 11,200 kcal / kg have excellent potential as a fuel for the drying process. LPG is not poisonous is one of the advantages to be used as fuel for drying food. Another advantage of LPG is easily controlled temperatures generated.

For the drying capacity of 1 ton of grain needed a power of 24 kW, equivalent to 20,650 kcal / h, requiring LPG as much as 1.8 kg / h.

Planned drying capacity of 2 tons with grain moisture content is assumed by an average of 25% wet basis, dried to 14% wet basis, was determined using a drying air temperature of 53ºC, lasts for 8 hours. From the calculations, the needs of the mass flow rate of the inlet air heat exchangers amounted to 6,600 kg / h.

Heat exchangers type is cross flow heat compact exchangers, size of 0.3 m long, 0.3 m wide and 0.2 m high with a plain surface shape of fin surface 2.0 as shown in Figure 7 respectively for the air side and the exhaust gas side. From calculation [7], the drying air temperature from heat exchangers is 54.3 °C as shown in Table 2.

Figure 7. Compact heat exchanger

Dryer air temperature from heat exchangers of 54.3 °C on the calculation results can already be used as a drying temperature according to the recommended temperatures for drying grain ranged between 43 ºC to 55 ºC [8].

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To produce a drying air temperature in accordance with the plan can be adjusted some parameters. Setting out the drying air temperature heat exchangers can be recalculated iteratively by adjusting several variables, among:

1. Lowering the temperature of the exhaust gases entering the heat exchangers.
2. Adjust the dimensions of heat exchangers.
3. Set the mass flow rate of the inlet air heat exchangers.
4. Change the material and shape of the fin heat exchangers.

For example, to dry the grain as much as 1 ton, set dryer temperature by 53 °C, it takes the mass flow rate of air exhaled by the blower is 3,300 kg / h and the drying time of 8 hours. By using the graph in Figure 8 can be determined exhaust gas temperature required for entry to the heat exchangers is at a temperature of about 200 °C.

TABLE 2. RESULTS OF CALCULATION

No.	Description	Symbol	Unit	Air	Exhaust gas
I	PRELIMINARY DATA / RESULTS MEASUREMENT				
1	Inlet temperature	T_{in}	°C	27	357
2	Mass flowrate	$\dot{m}$	kg/h	6600	636
II	HEAT EXCHANGERS CHARACTERISTICS				
A	Dimensions				
1	High	x	m	0.200	
2	Wide	y	m	0.300	
3	Long	z	m	0.300	
4	Volume	V	m^3	0.0180	
B	Plat fin surfaces			2.00	2.00
1	Transfer area/volume between plates	β_{ud}	m^2/m^3	249.70	249.70
2	Plat spacing	b	m	0.0190	0.0190
3	Hydraulic diameter	4_{rh}	m	0.0140	0.0140
4	Fin thicknes	δ	m	0.0008	0.0008
5	Plate thickness between the exhaust gas and air	a	m	0.0024	0.0024
C	Ratio of total heat transfer area to the total volume	α	m^2/m^3	110.85	110.85
D	Heat transfer area for each side	A	m^2	1.9953	1.9953
E	The ratio of free flow area and frontal flow area	σ		0.3880	0.3880
F	Free flow area	A_c	m^2	0.0233	0.0233
G	Reynolds number	Re		57584	4063
H	Stanton-Prandtl number	$StPr^{2/3}$		0.0023	0.0038
I	Friction factors	f		0.0055	0.0102
J	Heat transfer coeficient	h	$W/m^2.K$	3966.4	679.8
K	Fin efectifeness	ηf		0.4500	0.8000
L	Surface effectiveness	ηo		0.9835	0.9940
M	Total heat transfer coeficient	U	$W/m^2.K$	575.9217	
N	Number of Thermal Units	NTU		1.6463	
O	Heat Exchanger Effectiveness	ε		0.8020	
P	Outlet temperatures	T out	°C	**54.30**	92.36

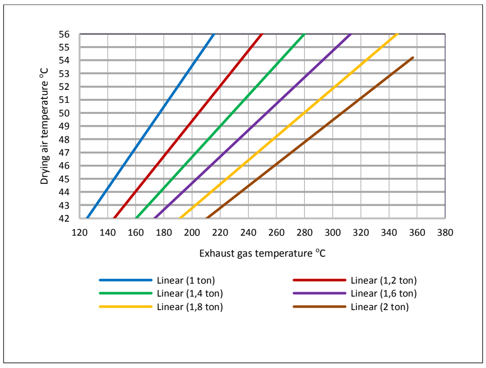

Figure 8. Relationships between exhaust gas temperature and drying air temperature and drying capacity for 8 hours drying time according heat exchangers designed

The use of LPG burner only when the drying process is still underway and the milling process has stopped operating before drying target is reached. Hot air exhaled by the LPG burner supplied by a blower that also serves dryer air flow while the milling process progresses.

Selection of LPG burner adjusted to the results of the calculation of the energy needs for grain drying capacity of 1 to 2 tons, amounting to 24 kW to 48 kW. Based on the characteristics of the LPG burner on the market for FBR Gas burner serie X Figure 10 [9], the type of gas burner in accordance with the energy requirement for drying capacity of 1 to 2 tons is FBR gas burner type X1 which can operate in the power range 23 kW to 58 kW.

V. CONCLUSION

From the measurement, calculation, design and testing of heat exchangers and furnaces for drying grain LPG obtained several conclusions, among others:

[1] Mitsubishi 6D16 diesel engine which is used as propulsion engines emit exhaust gases rice mill which has the potential to dry the grain as much as 2 tons.

[2] The design of heat exchanger made in accordance with the characteristics of the exhaust gas of diesel engines Mitsubishi 6D16 is a compact heat exchanger measuring length and height of each 0.3 m, 0.3 m and 0.2 m, using a fin-shaped 2.0 plain fin surfaces made of aluminum material with a thickness of 0.8 mm.

[3] LPG gas burner FBR X1 type that can operate at power 23 kW to 58 kW, was chosen as a substitute for the drying furnace based conformity with the characteristics of the hot air out of the heat exchanger.

[4] The result of the calculations used to design heat exchangers and dryers (dryer) refers to the condition of grain with initial moisture content of 25% and the final moisture content of 14% and a duration of drying for 8 hours at 82% relative humidity.

[5] The use of LPG as a burner substitution besides quite economical, also non-toxic and more practical when the exchange process from the exhaust gas to LPG and vice versa.

[6] Using the exhaust gas and LPG in hybrid for drying besides more economical, it is also more environmentally friendly.

[7] The exhaust gas as a primary energy source to operate during the milling process takes place, then the LPG burner hybrid operation when the grinding process is finished and the drying process has not been completed. This process takes place in an integrated manner with rice milling unit.

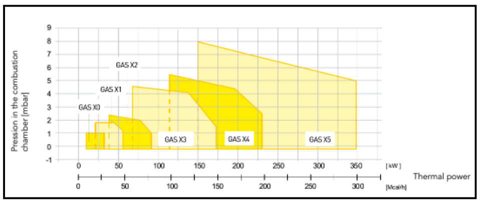

Figure 10. LPG burner characteristic diagram [9]

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